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Chapter 7. Sampling and Estimation

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Chapter 7. Sampling and Estimation

INTRODUCTION

This chapter discusses the sampling and estimation procedures used in the 1980 census. There were three sampling operations; the first involved what is termed the basic design, that is, the sampling and estimation procedures associated with the basic long-form sampling scheme. In addition to the basic sample design, two sampling and two estimation procedures were implemented. One involved subsampling long-form questionnaires on which the place-of-work and migration data items would be coded and a second involved designating a subsample of enumeration districts (ED's) to produce provisional estimates for selected geographic areas (termed the Early National Sample). This chapter provides details for the sampling, estimation, and variance estimation procedures used for each of these samples. Appropriate references for each of these procedures are provided at the end of this chapter.

SAMPLING

Basic Design

The 1980 census used two household questionnaires. The first, called the 100-percent, or "short," form, requested basic information for every person and housing unit (e.g., age, race, relationship to householder, number of rooms, and value or rent). The sample, or "long," form asked the 100-percent questions plus additional ones for a sample of persons and housing units. The basic sampling unit was the housing unit, including all occupants. For persons living in group quarters, the sampling unit was the person.

Two sampling rates were employed. In incorporated places of less than 2,500 persons (based on precensus estimates), one-half of all housing units and units and persons in group quarters were to be included in the sample. In all other places, one-sixth of the housing units or persons in group quarters were sampled. The purpose of this scheme was to provide relatively more reliable estimates (especially of per capita income) for small places.

The sample designation method depended on the data-collection procedures. In about 95 percent of the country, the census was taken by the mailout/mailback procedure. (See ch. 5.) For these areas, the computerized mailing lists were sorted geographically, and every sixth unit (for 1-in-6 areas) or every second unit (for 1-in-2 areas) was designated as a sample unit by computer. These designations were reflected in the mailed-out questionnaire and the followup address registers. (See chs. 3 and 5.)

In nonmailout/mailback, i.e., "conventional" areas, a blank listing book with designated sample lines (every sixth or every

second line) was prepared for the enumerator. Beginning about Census Day, the enumerator systematically canvassed the area, listed all housing units in the listing book in the order they were encountered, collected completed short-form questionnaires, and asked the sample questions about any household and/or housing unit listed on a designated sample line. (See ch. 5.)

Since the basic sampling procedure for the census involved varying rates (either 1 in 6 or 1 in 2) based on precensus estimates of the size of the incorporated place, the *expected* sampling rate for any geographic area varied, depending on the composition of the area with respect to incorporated places of less than 2,500 persons and of 2,500 or more persons. For the United States as a whole, 18.2 percent of the population and 18.4 percent of the housing units tabulated were enumerated on sample questionnaires. The effect of the two samplings used is illustrated by the fact that in urban areas, 15.8 percent of the population and 15.8 percent of the housing units were enumerated on sample questionnaires as contrasted with 24.9 percent of the population and 25.7 percent of housing units in rural areas. More detailed tabulations of the actual sampling rates for population and housing units for various levels of geography can be found in 1980 Census of Population, *General Social and Economic Characteristics*, series PC80-1-C1, and 1980 Census of Housing, *Detailed Housing Characteristics*, series HC80-1-B1.

Subsampling for Coding Certain Data Items

Sample processing included clerical coding of a number of written-in responses. After this had been underway for about 2 months, it was decided to cut costs by reducing the number of items to be coded. This was done by subsampling the sample questionnaire in each work unit (which normally represented one ED) and coding only half of the commuting (place-of-work and travel time) and migration (residence 5 years ago) responses while continuing to code all other written-in responses. In work units where the selected data items already had been coded, all sample questionnaires were included in the tabulations for those items.

Early National Sample

Census long-form information was collected from a sample of persons and housing units using the sampling procedures described above. As clerical editing and coding were required on these forms, sample data normally were released later than complete-count data. Budgetary and other problems introduced additional delay in the coding operation on the full census sample. An Early National Sample (ENS), therefore, was designed to provide data users early access to sample data on selected social, economic,

and housing characteristics for the United States, each State and the District of Columbia, and for the 38 standard metropolitan statistical areas (SMSA's) with 1 million or more persons. The sample, of slightly more than 1.5 percent of the housing units and persons in the United States, was drawn to provide certain minimum levels of reliability on estimates of per capita income for each of the above geographic areas, and the coding and editing of its questionnaires were expedited. A supplementary report, *Provisional Estimates of Social, Economic, and Housing Characteristics*, PHC80-S1-1, was published in the spring of 1982, at least 6 months earlier than corresponding data could have been published from the full census sample.

The ENS can essentially be viewed as a stratified two-stage sample of ED's and of persons and housing units within the selected ED's. The ED's in the Nation were stratified into 98 strata; 48 strata consisting of the whole or State portions of the 38 SMSA's with 1 million or more persons; 24 strata consisting of the balances of the 24 States containing a portion of one or more of the 38 SMSA's; and 26 strata consisting of the 26 States that did not contain any portion of the 38 SMSA's. For the first stage, the 1980 census ED's were arranged into clusters, which were sampled systematically with probability proportional to size. The ENS sample included a total of 17,143 ED's—approximately 5 percent of all ED's in the United States. The second stage was simply the persons and housing units chosen for the census sample within the selected ED's. The use of ED's as the first-stage unit was required so the selected ED's could be given priority status during the normal census coding operations. It was also not possible to sample within ED's due to the administrative requirements of the census processing operations.

ESTIMATION

Basic Sample and the Subsampled Items

A series of discussions with Bureau staff in the subject-matter, computer-support, and data-publication areas indicated that any estimation procedure used for the 1980 census would have to result in the assignment of weights to individual sample person and housing-unit records. These records would subsequently be stored on data files that had undergone various computer edits for accuracy and consistency. For any census tabulation area, a characteristic total would then be estimated by simply summing the weights assigned to the appropriate sample person or housing-unit records. It was also determined that any estimation procedure selected to assign weights to sample records would have to meet the following criteria:

1. Only a single weight was to be assigned to each individual sample person or housing-unit record. This constraint was imposed because the massive amount of data published would make it infeasible to store, control, and utilize different weights for each data item.
2. The assigned weights were required to be integers. This was necessary for data users' convenience, since it eliminated problems of differences due to rounding between data tables with similar marginal categories. It was also desirable because it would facilitate internal Bureau review of the complex weighting and tabulation programs.

3. The sample estimates of certain characteristics collected for the entire population were to equal the complete count figures. This agreement was required for total population and housing-unit counts for as many tabulation areas as possible. Agreement between the sample estimates and complete-count (100-percent) figures for other characteristics such as age, race, sex, and Spanish origin were also to be achieved whenever possible. This constraint was imposed primarily for the convenience of the data user.
4. The estimation procedure was to dampen the effect of any bias that occurred in sample selection.

In general, the estimation procedure dealt with groups of records within specially defined areas called weighting areas (described below). Within each weighting area, complete counts and sample counts were obtained for various characteristics. For these characteristics, the sample was weighted to agree with the complete counts of these same characteristics, using an iterative procedure (as discussed below) to assign weights to the sample records within each weighting area.

Background and Research

In the 1960 census, estimates based on sample data were derived by using a post-stratified ratio estimation procedure. Each sample record was first classified into a ratio estimate group. There were 44 age, sex, and color groups for persons, and 7 groups for housing units by color of occupants, occupancy, and tenure. The complete count for each group was determined and weights were assigned to the sample records to sum the complete count for the group. It was sometimes necessary to combine groups to meet conditions imposed to control the bias usually present in ratio estimation procedures.

Experience with the 1960 estimator suggested that the procedure should incorporate household size in the definition of the ratio estimate groups. However, the number of ratio estimate groups defined by expanding each of the 44 groups by 6 household size categories could not be used efficiently by an estimator of the type used in 1960, and other estimators were therefore considered.

In choosing the estimator to be used in 1970 census, the following criteria were considered: The estimator should (1) dampen the effect of any biases that occurred in sample selection, (2) reduce the variance of sample estimates, (3) improve the consistency between complete counts and sample estimates, (4) be economical to execute, and (5) permit reasonably accurate estimates of sampling error to be computed. After the 1960 census, the properties of a number of different ratio estimation procedures were examined and the so-called "raking" ratio estimation procedure was used. Prior to the 1980 census, it was decided to conduct an empirical and theoretical study (using 1970 census data) to compare alternative estimation procedures including a simple inflation estimator, a post-stratified ratio estimator, and the "raking" ratio estimator. In addition, various characteristics, for which sample and complete count totals were available, were tested in conjunction with the post-stratified and raking ratio estimators. Considering the same criteria for choosing an estimator as noted above, the results of the research indicated that the raking ratio estimator using the groups listed later in this

section was preferable, particularly with respect to controlling the effect of sampling biases. Convergence properties of this estimator were also investigated.

Definition of Weighting Areas

Each State was divided into weighting areas prior to performing the raking ratio estimation procedure. Weighting areas were, in general, contiguous portions of geography that closely agreed with census tabulation areas within a county and never crossed county or State boundaries. Weighting areas were required to have a minimum sample of 400 persons. In counties with a sample count of less than 400 persons, the minimum sample size requirement was relaxed to permit the entire county to be a weighting area.

Ratio Estimation Groups and Weighting Procedure

Within a weighting area, the raking ratio estimation procedure for persons was performed in three stages. For persons, the first stage employed 17 household type groups. The second stage used two groups—householders and nonhouseholders. The third stage could potentially use 160 age-sex-race/ Spanish-origin groups. The stages were as follows:

Stage I—Type of Household	
Group	
	Persons in housing units with a family with own children under 18:
1	2 persons in housing unit
2	3 persons in housing unit
3	4 persons in housing unit
4	5 to 7 persons in housing unit
5	8 or more persons in housing unit
	Persons in housing units with a family without own children under 18:
6-10	2 persons in housing unit through 8 or more persons in housing unit
	Persons in all other housing units:
11	1 person in housing unit
12-16	2 persons in housing unit through 8 or more persons in housing unit
17	Persons in group quarters
Stage II—Householder/Nonhouseholder	
Group	
1	Householder
2	Nonhouseholder (including persons in group quarters)
Stage III—Age/Sex/Race/Spanish Origin	
Group	
	White:
	Persons of Spanish origin:
	Male:
1	0 to 4 years of age
2	5 to 14 years of age
3	15 to 19 years of age

4	20 to 24 years of age
5	25 to 34 years of age
6	35 to 44 years of age
7	45 to 64 years of age
8	65 years of age or older
	Female:
9-16	Same age categories as groups 1 to 8
	Persons not of Spanish origin:
17-32	Same age-and-sex categories as groups 1 to 16
	Black:
33-64	Same age-sex-Spanish origin categories as groups 1 to 32
	Asian, Pacific Islander:
65-96	Same age-sex-Spanish origin categories as groups 1 to 32
	Indian (American) or Eskimo or Aleut:
97-128	Same age-sex-Spanish origin categories as groups 1 to 32
	Other (includes races not listed above):
129-160	Same age-sex-Spanish origin categories as groups 1 to 32

Within a weighting area, the first step in the estimation procedure was to assign each sample person record an initial weight. This weight was based on the ratio of the 100-percent population count of the ED containing the sample person record to the unweighted sample count of persons in that ED. The initial weight was calculated separately for persons in occupied housing units and those in group quarters.

The next step in the estimation procedure was to combine, if necessary, the groups in each of the three stages prior to the repeated ratio estimation in order to increase the reliability of the ratio estimation procedure. For the first and second stages, any group that did not meet certain criteria concerning the unweighted sample count or the ratio of the complete count to the initially weighted sample count was combined, or collapsed, with another group in the same stage according to a specified collapsing pattern. At the third stage, the "other" race category was collapsed with the "White" category before applying the above collapsing criteria as well as an additional criterion concerning the number of complete-count persons in each category.

As a final step, the initial weights underwent three stages of ratio adjustment, using the groups listed above. At the first stage, the ratio of the complete census count to the sum of the initial weights for each sample person was computed for each stage-I group. The initial weight assigned to each person in a group was then multiplied by the stage-I group ratio to produce an adjusted weight. In stage II, the stage-I adjusted weights were again adjusted by the ratio of the complete census count to the sum of the stage-I weights for sample persons in each stage-II group. Finally, the stage-II weights were adjusted at stage III by the ratio of the complete census count and the sum of the stage-II weights for sample persons in each stage-III group. The three stages of adjustment were performed twice (two iterations) in the order given above. The weights obtained from the second iteration for

stage III were assigned to the sample person records. However, to avoid complications in rounding for tabulated data, only whole-number weights were assigned. For example, if the final weight for the persons in a particular group was 7.2, then one-fifth of the sample persons in this group were randomly assigned a weight of 8 and the remaining four-fifths received a weight of 7.

Separate weights were derived for tabulating the place-of-work, travel time, and migration data items. The weights were obtained by adjusting the weight derived above for persons on questionnaires selected for coding by the reciprocal of the ED coding rate and a ratio adjustment to ensure that the sum of the weights and the complete-count total population figure would agree.

The ratio estimation procedure for housing units was essentially the same as that for persons. The major difference was that the occupied housing-unit ratio estimation procedure was done in two stages and the vacant housing-unit ratio estimation procedure was done in one stage. The first stage for occupied housing units employed 16 household type categories and the second stage could potentially use 190 tenure-race-Spanish origin-value/rent groups. For vacant housing units, three groups were utilized. The stages for the ratio estimation for occupied housing units were as follows:

Stage I—Type of Household	
Group	
	Housing units with family with own children under 18:
1	2 persons in housing unit
2	3 persons in housing unit
3	4 persons in housing unit
4	5 to 7 persons in housing unit
5	8 or more persons in housing unit
	Housing units with family without own children under 18:
6-10	2 persons in housing unit through 8 or more persons in housing unit
	All other housing units:
11	1 person in housing unit
12-16	2 persons in housing unit through 8 or more persons in housing unit
Stage II—Tenure/Race and Origin of Householder/Value or Rent	
Group	
	Owner-occupied units:
	White (householder):
	Persons of Spanish origin (householder):
	Value of house:
1	\$0 to \$9,999
2	\$10,000 to \$19,999
3	\$20,000 to \$24,999
4	\$25,000 to \$49,999
5	\$50,000 to \$99,999
6	\$100,000 to \$149,999
7	\$150,000 or more
8	Value not collected
	Persons not of Spanish origin:
9-16	Same value categories as groups 1 to 8

	Black:
17-32	Same value-Spanish origin categories as groups 1 to 16
	Asian, Pacific Islander:
33-48	Same value-Spanish origin categories as groups 1 to 16
	Indian (American) or Eskimo or Aleut:
49-64	Same value-Spanish origin categories as groups 1 to 16
	Other (includes races not listed above):
65-80	Same value-Spanish origin categories as groups 1 to 16
	Renter-occupied units:
	White:
	Persons of Spanish origin:
	Rent categories:
81	\$1 to \$59
82	\$60 to \$99
83	\$100 to \$149
84	\$150 to \$199
85	\$200 to \$249
86	\$250 to \$299
87	\$300 to \$399
88	\$400 to \$499
89	\$500 or more
90	Other renter
91	No cash rent
	Persons not of Spanish origin:
92-102	Same rent categories as groups 81 to 91
	Black:
103-124	Same rent-Spanish origin categories as groups 81 to 102
	Asian, Pacific Islander:
125-146	Same rent-Spanish origin categories as groups 81 to 102
	Indian (American) or Eskimo or Aleut:
147-168	Same rent-Spanish origin categories as groups 81 to 102
	Other (includes races not listed above):
169-190	Same rent-Spanish origin categories as groups 81 to 102
	Vacant housing units:
1	Vacant, for rent
2	Vacant, for sale
3	Other vacant

The estimates produced by this procedure realized some of the gains in sampling efficiency that would have resulted if the population had been stratified into the ratio estimation groups before sampling, and the sampling rate applied independently to each group. The net effect was a reduction in both the standard error and the possible bias of most estimated characteristics to levels below what would have resulted from simply using the

initial (unadjusted) weight. A byproduct of this estimation procedure was that the estimates from the sample would, for the most part, be consistent with the complete-count figures for the population and housing unit groups used in the estimation procedure.

The above description of the weighting procedure is only a very general overview of a rather complex operation. Several changes were made to the procedure as a result of Statistical Methods Division's (SMD) review of output from test runs that were conducted on three States—Delaware, Montana, and Rhode Island. The reference section at the end of this chapter provides a listing of the documentary memorandums relating to the weighting procedure, including the definition of weighting areas, the collapsing procedures used, and the subsequent modifications to these procedures.

Weighting Approval Process

In the 1980 census, the weighting operation was approved in two phases for each State as the States were processed. For phase 1, Bureau headquarters staff received preliminary output from the weighting operation that gave both detailed and summary information concerning the weighting operation for *each* weighting area in a State. The output included certain demographic counts, displays of marginal weighting matrix counts, diaries of the weighting area formation and weighting matrix collapsing, and other analytical data relating to the weighting operations. For phase 2, the staff examined the phase-1 output, requested more detailed output as required for selected weighting areas, and identified and corrected problems.

Early National Sample

The estimation procedure for the ENS was essentially the same as that used for the basic sample except for the definition of weighting areas and the rules for collapsing the cells of the weighting arrays. For the ENS, each of the 98 sampling strata discussed earlier was designated as a weighting area, and the collapsing rules were modified to take into account the larger weighting area sizes. The weighting arrays used for the raking ratio procedure were identical to those used for the basic sample. For population characteristics, the weighting array was three-dimensional, using column categories defined by race, Spanish origin, sex, and age; row categories defined by family type and size of household; and categories for the third dimension defined by householder/nonhouseholder status.

For occupied-housing-unit characteristics, the two-dimensional weighting array used column categories defined by tenure, race/Spanish origin of the householder, and value/rent, and row categories defined by family type and size of household. The weighting approval process was also essentially the same as that used for the basic sample modified slightly to accommodate the design features of the ENS.

SAMPLING VARIABILITY

Introduction

Statistics based on a sample almost always differ somewhat from figures that would have been obtained if a complete cen-

sus had been taken using the same questionnaires, instructions, and enumerators. Sample results are also subject to the same response, reporting, and processing errors which would be present in data from a complete census.

So that sample statistics from the census would be properly interpreted, a statement on their reliability appeared in census publications. The estimates of reliability reflected sampling error and the effect of the estimation procedure but did not reflect the full effect of response or processing variance, or any effect of bias arising in collection, processing, or estimation.

Presenting Sampling Errors

Basic design—A major concern in the choice of a method of presenting sampling errors arose from the number of statistics produced. To compute and show the sampling error for each published characteristic in each tabulation area would have been costly and time-consuming, as well as double the number of pages needed to present the results in published volumes. It was decided, therefore, to group the individual census items into homogeneous classes and show in the publications the average of the sampling errors for the items in each class.

Almost all of the statistics tabulated from the census sample can be characterized as 0-1 variates; that is, the person or housing unit is assigned the value one if that person or housing unit possesses the characteristic, and zero otherwise. The design of the census sample and the ratio estimation procedure used suggested that the variances would usually have a fairly simple relationship to those arising from a simple random sample of the same size. This led to a decision to present the sampling errors in the form of "design effects," which are the ratio of the estimate of the variance of the census sample to the variance for a 1-in-6 simple random sample. Design effects were calculated for a set of data items within each weighting area. The ratios were averaged over the items in the class and over weighting areas, and the square root of the average was used in determining the standard error for all statistics for the class.

This decision led to the following method of presenting data on sampling errors. Each 1980 census report contained three tables. Two of the tables showed the standard errors of a 1-in-6 simple random sample for 0-1 characteristics. One of the tables applied to estimates of totals, the other one to percentages. They showed the values of $5\hat{Y}(1-\hat{Y}/N)$ where N is the size of the area (population or housing units) and \hat{Y} is the estimated total and $5\sqrt{\hat{p}(100-\hat{p})}$ where B is the base of the estimated percentage \hat{p} .

The third table reflected the design effect, that is, it provided adjustment factors to be applied to either of the first two tables. Readers were required to find the adjustment factor for the subject area of interest (e.g., language usage or number of rooms) in the third table. They then multiplied the factor shown in that table by the appropriate standard error from one of the first two tables to obtain an estimate of the standard error of the census statistic of interest. The design effects table also reflected variability in the observed sampling rates that occurred due to the census sample design (i.e., due to the two sampling rates that were used).

Early National Sample (see p. 4)—The ENS report contained four tables for estimating standard errors. Two of the tables showed

the unadjusted standard errors associated with a simple random sampling design. One of the tables applied to estimates of total, the other one to percentages.

They showed the values of

$$SE(\hat{Y}) = \sqrt{f \hat{Y} (1 - \hat{Y}/N)} \text{ and } SE(\hat{p}) = \sqrt{\frac{f \hat{Y}}{N^2} (1 - \hat{Y}/N)}$$

where N is total population or housing units, \hat{Y} is the estimate of the characteristic total, \hat{p} is the estimated percentage, and f is the average value of the initial weighting factors ($f \doteq 62$), approximately the inverse of the overall combined sampling fraction for the country.

The third table showed groupings of publication areas (United States, each State and the District of Columbia, and 38 SMSA's with 1 million or more persons) that had to be used in conjunction with the fourth table. The fourth table reflected the design effects for publication areas; it provided factors to be applied to either of the first two tables. The data user was required to obtain the unadjusted standard error from either of the first two tables, then find the publication area of interest in the third table and obtain its publication-area group number, and finally use the fourth table to obtain the factor for the type of data item of interest (e.g., labor-force status, veteran status, school enrollment) and the publication-area group given in the third table. Then the data user multiplied the adjustment factor shown from the fourth table by the unadjusted standard error to obtain an estimate of the standard error of the ENS statistic of interest.

Variance Estimation for the Census

Basic design—To produce the design effects, it was necessary to estimate the variance of the census statistics. Because a complex estimator and a systematic sample of clusters (households) were used, no simple mathematical formula could be derived that would directly estimate the variance from the census sample. The variance of census estimates was therefore approximated by a random group procedure.

The general procedure was to systematically split the sample in each weighting area into 25 subsamples and, for a particular characteristic, to calculate the sum of squares of the subsample totals minus the average of the 25 subsample subsample totals. The general form of the variance estimator for a particular estimate (\hat{X}) is as follows:

$$\text{Var}(\hat{X}) = (1 - f_0) 25 \frac{\sum_{i=1}^{25} (\hat{X}_i - \hat{X}/25)^2}{24}$$

Where:

\hat{X}_i is the weighted total of the characteristic of interest in a weighting area based on the records assigned to the i th subsample

\hat{X} is the sum of the 25 values of \hat{X}_i ($\hat{X} = \sum_{i=1}^{25} \hat{X}_i$)

f_0 = observed sampling fraction in the weighting area; in terms of persons or housing units as appropriate.

Variance estimates were produced for over 1,000 population and housing characteristics that appeared on summary tape file (STF) 3.

The choice of the particular variance estimation technique was also based on the results of an empirical research study conducted prior to the 1980 census. This study was designed to compare the reliability and accuracy of four commonly recommended procedures for estimating the variance of the complex estimator used in the 1980 census.

Early National Sample—The variance estimates for the ENS were calculated using the variance estimator appropriate for a with-replacement probability proportional to size sample design. As for the basic sample, variance estimates were produced for each population and housing unit characteristic appearing on the STF 3 prepared for the ENS.

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